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STUDY PROJECT

SPACE-BASED MULTISPECTRAL IMAGERY: CURRENT AND FUTURE APPLICATIONS AND IMPLICATIONS TO THE UNITED STATES ARMY

BY

LIEUTENANT COLONEL JAMES M. WEILBRENNER, SC

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U.S. ARMY WAR COLLEGE, CARLISLE BARRACKS, PA 17013-5050

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SPACE-BASED MULTISPECTRAL IMAGERY: CURRENT AND FUTURE APPLICATIONS AND IMPLICATIONS TO THE UNITED STATES ARMY

AN INDIVIDUAL STUDY PROJECT

by

Lieutenant Colonel James M. Weilbrenner, SC

Colonel R. F. Hervey
Project Adviser

U.S. Army War College
Carlisle Barracks, Pennsylvania 17013
2 February 1990

ABSTRACT

AUTHOR: James M. Weilbrenner, LTC, SC

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The Army expends considerable effort in attempts to pierce the fog of battle. Multispectral imagery (MSI), an emerging technology, has the ability to reduce this fog. Although MSI has been used by civil agencies for more than 15 years, the Army is just beginning to realize and exploit its capabilities. One of the major attractors of MSI is the unclassified nature of its data which is obtained from civil sensors. Unlike military reconnaissance data which is usually highly classified, operational and tactical commanders at all levels can use MSI products. This study provides a thorough description of MSI including its space-based assets and civil uses. Current Army utilization is also reviewed. The study concludes with an examination of possible future applications and implications. Research for the project included a comprehensive review and analysis of a wide spectrum of literature and personal interviews with experts in the MSI field. In addition to showing how MSI can benefit the Army, the study offers several recommendations to facilitate the development and utilization of MSI technology in the Army.

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CHAPTER I

INTRODUCTION

The Clausewitzian fog of the battlefield continues today as the major nemesis of operational and tactical commanders. The Army expends much effort in attempts to pierce this fog and thereby improve the decision-making of its warfighters. In this effort, the Army has taken to the new high ground--space. To most in the Army, space equates to communications, reconnaissance, and weather satellites and Star Wars or the Strategic Defense Initiative. With a few exceptions in tactical communications, most soldiers regard space systems as national assets used only at very high levels with little benefit to them. Recognizing that its ability to successfully implement the AirLand Battle doctrine depends increasingly on the imaginative integration of space assets into its functional areas, the Army has become quite serious about its involvement in space. The recent establishment of the Army Space Command as a full-fledged partner of the United States Space Command and the Army Space Institute as the Army proponent for space serve as recent examples of the Army commitment to space. Of the four space mission areas, force enhancement--the use of space assets to support terrestrial operations--holds the most potential to benefit the Army during the next decade.

How many commanders would welcome a capability

enabling them to identify an enemy camouflage system and what's beneath it, to warn of radiation or chemical contaminated areas, or to receive an extremely thorough intelligence preparation of the battlefield before they depart their home base? These are only a few of the many currently available or imminent military capabilities to be obtained from space-based multispectral imagery (MSI).

SCOPE

This study will provide a thorough description of MSI, discuss current Army applications of it and offer a prognosis of future implications and applications for the Army. It will conclude with a number of recommendations regarding MSI's future in the Army.

LIMITATIONS

Although MSI can be an extremely technical subject, this study attempts to make the technology comprehensible for the average, non-technical reader. In addition, this study uses only unclassified information.

CHAPTER II

BACKGROUND

A common level of understanding will enable us to better understand and appreciate the application of multispectral imagery (MSI) to the Army. The following background information will define the process of MSI, provide a brief history of its evolution, describe current MSI satellites, delineate future MSI projects, and indicate current civil uses of MSI.

DEFINITION

MSI generally refers to a process for the simultaneous acquisition of remote sensing data in two or more spectral bands. Remote sensing refers to the study of objects or phenomena from a distance by a system or systems not in contact with the object or phenomenon being investigated. A spectral band denotes a segment of the electromagnetic spectrum bounded by two wavelengths or frequencies. The electromagnetic spectrum of interest in MSI consists of bands in the visible, infrared, and microwave ranges. MSI or, as it is sometimes referred, multiband imagery (MBI) results from the simultaneous observation or sensing of the same target by a system of spectral band filters and sensors designed to measure the intensity of the electromagnetic radiation that is reflected or emitted by the target at several different wavelengths or frequencies.[1] This sensing is possible by virtue of the fact that every object and every terrain feature absorbs, reflects, and emits electromagnetic energy at specific

distinctive wavelengths--most of which are not in the visible range.[2] When collected, compared, and analyzed, these spectral characteristics comprise a unique signature or footprint; thus it becomes possible to distinguish one object from others and to obtain information relating to the object's size, shape, density, and other physical and chemical properties.[3]

A number of advantages accrue from the simultaneous sensing of several portions of the electromagnetic spectrum in addition to the visual. First, some objects appear clearly at one frequency, but they may not be discernible at another.[4] Simultaneous images in various spectral bands may be compared, making it possible to discriminate between objects or phenomena which exhibit no apparent difference in the visual range.[5] Images from one spectral region may also be combined with those from another: thus a single composite image can be obtained, representing an optimum image for analysis.[6] Second, we can access new types of information which are not available from the visual range.[7] For example, the infrared sensor can produce thermal maps. Since all materials emit heat radiation of various intensities, temperature gradients can be important parameters for some applications such as monitoring water pollution or identifying a submerged nuclear submarine from the discharge of its reactor coolant into the surrounding ocean.[8] Finally, since longer wavelengths such as microwave are not obscured by clouds or darkness, microwave sensors can be used at night as well as day--thereby providing continuous, around-the-clock information.[9]

MSI Satellites

Although MSI can be obtained from ground, air, or space-based platforms, this study deals only with space-based satellite platforms. MSI satellites possess a number of advantages over other platforms, especially since they can provide images of large or remote areas through uniform and repetitive coverage.[10] Thus MSI can map large areas quickly and reliably monitor conditions that change with time.[11]

Current MSI satellites employ electro-optical technology which consists essentially of a telescope with a mirror in front of it; this instrumentation receives electromagnetic radiation from the earth by scanning rapidly back and forth as the satellite moves forward along its orbital path.[12] As the mirror scans, a detector converts the received energy into a digital data stream; the data may then be transmitted instantaneously to a ground station if one is in view of the satellite.[13] Each sweep of the mirror produces a line of picture elements or pixels.[14] A pixel is the electrical representation of the area on the ground sensed in a particular instant of time.[15] Many thousands of pixels make up an image scene.[16] Several different techniques for obtaining MSI are currently in use; they range from several sets of mirrors and detectors that are sensitive to different wavelengths to a spectrometer in the focal plane of the telescope to disperse the electromagnetic energy into different wavelengths directed to an array of detectors.[17] If the MSI satellite is not in view of a ground station, the data stream may be transmitted to a relay satellite which is in view of a

receiving station. Or the data may be stored in tape recorders on the MSI satellite until it is in view of a receiving station to which it may then transmit the data.[18] MSI generates tremendous amounts of data. For example, a single 9.5 inch square image digitized at 7,000 by 7,000 pixels contains 400 Mbits of data.[19]

Resolution

Two MSI sensor characteristics, spatial resolution and spectral resolution, merit special understanding. Spatial resolution indicates the system's ability to distinguish closely spaced objects on an image.[20] Several factors combine to determine the spatial resolution of a system. One, the instantaneous field of view (IFOV)--the area on the ground that a single pixel sees at any given instant--yields a reading of the predominant electromagnetic radiation in that IFOV.[21] A system cannot normally detect anything smaller than its IFOV, and it normally requires at least two-and-a-half pixels to distinguish an object.[22] Several factors affect spatial resolution: atmospheric conditions, sensor noise, camera shake, and the amount of contrast in the scene being observed.[23] But a crucial factor is the altitude of the satellite's orbit.[24] As might be expected, the closer to the ground the sensor is, the better the spatial resolution.[25] However, as spatial resolution increases, the breadth of vision or swath width decreases.[26] As a result, military reconnaissance satellites orbit from 200 to 500 kilometers above the Earth, and civil observation satellites use 500 to 1000 kilometer orbits.[27]

Spectral resolution denotes the system's ability to detect discrete information; it is directly related to the number of spectral bands sensed by the MSI satellite.[28] Since not all wavelengths can pass through the atmosphere, band selection is quite important in MSI design.[29] Wavelengths which can pass through the atmosphere include:

- --approximately 0.4 to 1.0 micrometers, encompassing reflected visible (such as blue, green, and red) and near-infrared light;
- --approximately 8 to 14 micrometers, thermal infrared, which reveals emitted heat; and
- --approximately 1 millimeter to over a meter, microwave, which is used for radar.[30]

We have previously noted the advantages of using several bands simultaneously. Clearly, multiband observation maximizes the collection of useful data.

Hyperspectral Imagery

A new technique derived from MSI is designed to increase spectral resolution. Hyperspectral imagery (HSI) uses not just a few spectral bands as in MSI; it uses literally hundreds of discrete bands to produce a tremendous number of discriminations which, when combined, form an incredibly detailed and precise fingerprint, greatly enhancing the potential use of this technology.[31] HSI may be ready for use in the next decade.[32]

Passive/Active

MSI satellites are categorized as being either passive or active.[33] The passive MSI system relies solely on the reception of electromagnetic energy that is reflected or radiated from the Earth and suffers serious limitations when the subject to be studied is covered by clouds or darkness.[34] All current MSI satellites are passive.[35] An active MSI satellite would be capable of overcoming such limitations by using its own radar to illuminate the target and then to detect the reflected energy.[36] Active MSI would thereby provide all-weather imagery at all hours of the day and night.[37] Needless to say, this technology is even more complex and requires a much larger power source--usually a nuclear reactor.[38] Numerous active systems are planned for the next decade.[39]

Image Processing

Once the ground station receives the data from an MSI satellite, the data can be immediately reconstructed and used.[40] However, the raw images cannot at this time be overlain with map data because of distortion introduced by both the angle at which the sensor makes its measurements and the curvature of the Earth.[41] So computer systems must be used to warp or transform the images onto standard map projections.[42] This adaptive kind of computer manipulation is just one of two general categories of computer analysis of MSI called image processing.[43] The other is enhancement.[44] This may be as simple as enhancing a line, edge, or shadow detail or varying the contrast to help the eyes differentiate even the most subtle

changes in shade.[45] Other much more sophisticated processes emphasize features with a particular orientation, form, intensity, or frequency.[46] They often produce images which have little in common with the original and can be interpreted only by specially trained personnel to whom they may reveal a wealth of information.[47] Some of these programs allow interactive manipulation by analysts.[48]

HISTORY

MSI, as it is understood and utilized today, began with the 1972 launch of the Earth Resources Technology Satellite (ERTS-1), later renamed Landsat 1.[49] This launch culminated years of efforts by National Aeronautics and Space Administration (NASA) scientists to obtain an Earth remote sensing capability as a follow-on to photographic experiments from NASA's Mercury, Gemini, and Apollo projects.[50] Built by General Electric as an improved and enlarged version of the proven Nimbus weather satellites, Landsat 1 would experiment in systematically surveying the Earth's surface to study the health of its crops and the potential development and use of its lands and oceans.[51] The scientific community quickly judged the experiment a success and immediately put its data to practical use in managing the food, energy, and environmental resources of the Earth.[52] The Landsat program, which launched its last satellite--Landsat 5--in 1984, made the United States the world leader in remote sensing technology during this period.[53]

Several noteworthy events occurred during this productive Landsat era. First, NASA established a policy that all Landsat data would be unclassified and then made available to the general public.[54] As the world's only Earth remote sensing program, Landsat provided data which was used by many federal agencies and state governments as well as a multitude of private companies, both domestic and foreign.[55] Second, the Landsat program was transferred from NASA to the National Oceanic and Atmospheric Administration (NOAA) in 1979 at a time of increasing fiscal concern.[56] For a variety of reasons--such as NASA's pullback from Landsat research and development efforts in favor of the shuttle program, NOAA's lack of experience in developing earth resources satellites, and NOAA's inability as an agency in the Department of Commerce to fare well in the fiscal process--the Landsat program went into decline.[57] Third, efforts by both the Carter and Reagan Administrations led to the 1984 enactment of the Land Remote Sensing Act, which directed the commercialization of the Landsat program and the resulting 1985 contract award to the Earth Observation Satellite Company (EOSAT), a joint venture of RCA Corporation and Hughes Aircraft Company.[58] This commercialization of Landsat was justified by a President Carter-appointed task force created to analyze the use and application of government satellites.[59] It concluded that the U.S. investment of one billion dollars in the Landsat program had yielded less return on investment than any other new technology.[60] The timing of commercialization could not have been worse. No work on replacement satellites for Landsat 5 had begun during this

period because of the uncertainty in program support and direction even though the Landsat satellites were engineered with a three-year expected life.[61] Also, due to federal budgetary concerns, EOSAT contract funding continually fluctuated.[62] Finally, during this period the United Nations emerged as the legislator and guardian of international laws pertaining to remote sensing of the Earth.[63] Its "open skies" policy dealing with the peaceful uses of outer space and the universal sharing of remote sensing technology was generally supported by the U.S.[64] Due to the "open skies" policy, the Carter Administration felt it necessary to keep the technology of military systems compartmented in the interest of national security.[65] As a result, a 10 meter resolution restriction was placed on U.S. civil satellites--resulting in a further stifling of the development of the Landsat program.[66]

The period since 1985 can be characterized at best as marginally hopeful for the U.S. Landsat program. Landsat 4 is only partially operational, and Landsat 5 has lost some of its redundancy.[67] Both have reduced data collection in order to prolong their lives.[68] EOSAT has gained funding for construction of Landsat 6 (expected launch date in 1991) and for a study of the commercial outlook for a Landsat 7.[69] Under EOSAT, the cost of Landsat data and products has increased greatly, questionable spending priorities (exemplified by the construction of an elaborate, state-of-the-art distribution center in Lanham, MD) have been established, and there has been little international cooperation (highlighted by EOSAT's refusal to adopt a

common tape format which would enable users to build archives of information from all of the many MSI satellite systems.[70] President Reagan's new U.S. space policy, which was announced on February 22, 1988, lifted the ban on resolution less than 10 meters and has affirmed a renewed commitment to the civil space program; hopefully, these initiatives will reverse the current state of the Landsat program.[71]

The fragmentation of Landsat program leadership and responsibility, sporadic funding support, and 1970's technology have opened the door to a number of competitors--primarily the French, Japanese, Canadians, and Russians.[72] In 1986, the French launched their first MSI satellite, Systeme Probatoire d'Observation de la Terre (SPOT).[73] Then in 1987, the Soviet Union launched the largest Earth observation system, COSMOS 1870.[74] Japan also moved into the MSI market in 1987 with the launch of its Marine Observation Satellite (MOS-1).[75] Clearly, the U.S. has lost not only significant market share in the highly competitive international remote sensing business, but also its position as the leader in MSI technology. We are in a catch-up mode now. If unsuccessful, the U.S. will then have to rely on foreign MSI satellites with their obvious implications.

CURRENT MSI SATELLITES

Landsat

Landsats 4 and 5 are currently operational in a near polar orbit which allows the satellites to image the same area every 16

days (referred to as an orbital cycle) at the equator and more frequently at higher latitudes.[76] At an orbital altitude of 705 kilometers, each satellite possesses two sensor systems: the Multispectral Scanner (MSS) and the Thematic Mapper (TM).[77] MSS has a ground pixel resolution of 80 meters and records data in two visible and two near-infrared (IR) bands.[78] TM, with a ground resolution of 30 meters, records data in three visible bands, one near-IR band, two middle-IR bands, and one thermal IR band.[79] In addition to improved spatial and spectral resolution, TM also offers an increased range of radiometric levels--256 compared with MSS's 64.[80] A radiometric level is the digital value to which the MSI sensor converts the received electromagnetic energy from Earth. The greater the range of radiometric levels, the more accurate will be the reproduced image scene. Landsats monitor and image a 185 kilometer swath of the Earth's surface.[81]

SPOT

SPOT 1 is in a polar orbit with a 26 day orbital cycle.[82] At an orbital altitude of 832 kilometers, this satellite carries two sensor systems using High Resolution Visible Range (HRV) scanning devices with no mechanical moving parts as in the Landsat sensors.[83] The multispectral sensor, with a resolution of 20 meters, collects data in two visible bands and one near-IR band.[84] The panchromatic sensor images a wide spectral region and provides a ten meter resolution.[85] SPOT also uses 256 radiometric levels.[86] The French satellite has a unique feature: its sensors can be pointed off from nadir at 0.6 degree

increments up to a maximum of 27 degrees on either side of the orbital path.[87] This allows it to image any 60 kilometer swath width within a 950 kilometer swath, over which it orbits.[88] In addition, this capability allows for the acquisition of stereo (three-dimensional) imagery and more frequent revisits of an area.[89] SPOT Image Corporation is the French counterpart of the U.S. EOSAT.[90]

Advanced Very High Resolution Radiometer

NOAA provides an MSI capability which piggybacks on its advanced Tiros polar-orbiting weather satellites at 800 kilometer altitudes.[91] Called Advanced Very High Resolution Radiometer (AVHRR), this system may be used when small-scale MSI data is inadequate for global coverage.[92] The sensor provides data with either 1.1 kilometer resolution or 4 kilometer resolution in one visible band, one near-IR band, one middle-IR band, and two thermal-IR bands.[93] AVHRR can provide repeat coverage every 12 hours and uses 1024 radiometric levels.[94]

MOS

Japan's MOS-1 is currently operational in a polar orbit which allows the satellite to image the same area every 17 days.[95] At an orbital altitude of 909 kilometers, it carries three sensor systems: the Visible and Thermal Infrared Radiometer (VTIR), the Multispectral Electronic Self-Scanning Radiometer (MESSR), and the Microwave Scanning Radiometer (MSR).[96] VTIR records data in one visible band with 0.9 kilometer resolution and three thermal-IR bands with 2.7

kilometer resolution over a 1500 meter swath.[97] MESSR records data in the same four bands as Landsat's MSS, but with a resolution of 50 meters and a swath width of 60 kilometers.[98] MSR is a radar system in the microwave region, with a 21 to 31 kilometer resolution over a 320 kilometer swath.[99] Japan sells its MSI data through its Remote Sensing Technology Center of Japan (RESTEC).[100]

COSMOS

The Soviets offer MSI with resolutions as low as 5 meters.[101] They currently provide only photographic film images--no data for further processing--and will not provide any imaging of socialist countries.[102] Soviet imagery products may be purchased from Soyuz Karta, their marketing organization.[103]

FUTURE PLANS

United States

The next MSI satellite for the U.S. will be Landsat 6, if it continues to be funded.[104] Current plans call for a 1991 launch.[105] Building on Landsat 5 technology, it will carry a number of improvements: wideband tape recorders; an Enhanced Thematic Mapper (ETM), which among other enhancements will include a panchromatic band with a 15 meter resolution; and a Sea Wide Field Sensor (SeaWiFS) (which combines the attributes of the AVHRR and the Coastal Zone Color Scanner), capable of sensing four visible, two near-IR, and two thermal-IR bands with a 1.13 kilometer to 4.5 kilometer resolution over a 2400 kilometer swath.[106]

Plans for a Landsat 7 are extremely vague; principally, they include enhancements to Landsat 6: higher resolution, more purpose-specific sensors, a pointable system, and a radar capability.[107] These plans are further complicated by the doubtful status of EOSAT.[108] Landsat 7 may have a different proprietor.

France

The French government is strongly committed to providing SPOTs 2, 3, and 4.[109] SPOTs 2 and 3 are identical to SPOT 1 and will be ready for launch in 1990 and 1992.[110] SPOTs 4 and 5 will be identical new designs and ready for launch in 1995 and 1999.[111] The new design incorporates a new vegetation sensor similar to the NOAA AVHRR, but it will use only one visible and one middle-IR band.[112] It will also be pointable with 1.2 kilometer resolution and 2200 kilometer swath.[113]

Japan

Japan is planning a 1992 launch of the Japan Earth Resources Satellite (JERS-1) with three sensors: a Synthetic Aperture Radar (SAR) using a single microwave band, a Visible and Near-Infrared Radiometer (VNR) using three visible bands and one near-IR band with a stereo capability, and a Short-Wave Infrared Radiometer (SWIR) using three or four middle-IR bands.[114] The sensors will provide 20 meter resolution over a 75 kilometer swath.[115]

European Space Agency

The European Space Agency plans to launch an Earth Resources Satellite (ERS-1) in 1992.[116] It will carry several instruments including a SAR with 30 meter resolution and 80 kilometer swath.[117]

Canada

Canada plans a 1990 launch of Radarsat, which employs SAR with 25 to 30 meter resolution and 500 kilometer swath.[118]

CIVIL USE

Civil use of MSI is nothing less than astounding. Limited only by imagination and more recently by cost, the applications of MSI continue to increase. With the continuing evolution of new image enhancement techniques using computers for image processing, most of the data on hand has barely been exploited. Although a relatively new science, MSI has become essential to world affairs. It is providing data on vital interests in such diverse specialties as cartography, geology, agriculture, forestry, oceanography, hydrology, disasters, and news.

In cartography, MSI has proven to be the only practical method to produce up-to-date, small scale maps of large regions. Its ability to provide data on remote areas which are extremely difficult to map by conventional methods and to record dynamic changes in the condition and use of the Earth's surface is unsurpassed.[119]

In agriculture and forestry, MSI provides the capability to monitor patterns of land use, forecast crop yields, control

pests, monitor rangeland, inventory livestock, detect crop stress, compile forest inventories, survey soils, monitor agricultural trespass on federal lands, identify the various species and varieties of plant life, and detect and monitor forest fires.[120]

MSI enables oceanographers to monitor ocean surface and subsurface conditions in order to better control ocean resources and ocean pollution like oil slicks, to prepare highly accurate hydrographic charts, to warn ships about icebergs and turbulent seas, and to guide fishermen to their catch.[121]

MSI allows geologists to detect possible mineral and petroleum locations by highlighting geologic faults, fractures, and concealed folds and to identify geothermal power sources and volcanic activity.[122]

Hydrologists use MSI to monitor snow and ice accumulations and melting patterns in order to obtain more accurate predictions of runoff.[123] This leads to better regulation of impounding and release of water in reservoirs, which in turn results in better flood control, irrigation, power production, and overall water management.[124]

In addition, MSI can contribute greatly to the prediction, prevention, and quick and effective response to natural or man-made disasters.[125] MSI data sharpens predictions of crop failures or areas of excessive snow melt. This can lead to appropriate hydrologic adjustments to prevent a flood. Potential famine areas can be predicted from crop studies, and appropriate relief planning can as well be initiated early.[126] Also, the

sources and distribution of pollution can be identified.[127]

Since MSI products comprise about the only commercially available worldwide overhead reconnaissance data, the news media have become avid users. MSI led to the exposure of the Chernobyl disaster and identification of Iranian Silkworm missile pads in the Persian Gulf to the general public.[128] These are only dramatic examples of MSI's contributions to international reporting. The media now has access to a "strategic eye in the sky" from which they can gather information on virtually any area of the globe--restricted only by the physical limitations of MSI.

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CHAPTER III

CURRENT ARMY APPLICATIONS

Although MSI has been heavily used in civil disciplines, its application to the military and, in particular, to the Army has been almost solely confined to the highly classified MSI associated with the National Technical Means. Only recently has the Army begun to examine and use the MSI capabilities associated with the civil MSI satellites. The community of interest remains quite small at this time, with most efforts centered around the Army Multiband Imagery Working Group. Its key players include the Army Space Institute, the Army Space Command, the Defense Mapping Agency, the Office of the Assistant Chief of Staff for Intelligence, the Office of the Chief of Engineers, the 18th Airborne Corps, the Special Operations Command, the U.S. Army Europe, the Army Engineer School, the Army Intelligence Center and School, the Army Cold Regions Research Laboratory and its Waterways Experiment Station, the Engineer Topographic Laboratory's Terrain Analysis Center, the U.S. Geological Survey's EROS Data Center, and the Army Intelligence Threat Analysis Center's Imagery Division. Although having good intentions, this diverse group has difficulty remaining focused. As a result, issues needing attention such as building a sound MSI exploitation architecture, establishing Army standards for the format of MSI data and its storage media, and guiding software enhancements continue to drag on with either partial or

no resolution.[1] Strong direction within the Army for MSI appears to be lacking.

SHORTCOMINGS

Up to now, the Army's interest in MSI has been confined almost totally to research and development (R&D). Only recently a memorandum of understanding (MOU) was signed between the Army and the U.S. Geological Survey (USGS).[2] A letter of instruction (LOI) implementing the MOU is currently being finalized. It provides procedural guidance to major commands and tactical units for the procurement of civil satellite MSI data, the production of customized/enhanced data products, and the acquisition of technical assistance.[3] In addition to delineating specific responsibilities and procedures, these two documents should result in more timely acquisition of data at a lower cost. These last two points are not insignificant. Past experience has shown that obtaining an MSI product can take approximately one month if it is in the current data base or two to three months if it is not.[4] This waiting period may be shortened to one day in some instances under the new LOI, which establishes a precedence system.[5] The second point--cost--is a major limiting factor in the use of MSI. Currently, Landsat images cost approximately $3000 per image scene (185 by 185 kilometer area), and SPOT images cost approximately $1900 per image scene (60 by 60 kilometer area).[6]

EXPLOITATION

MSI data can be purchased in either hard or soft copy formats, depending on how it will be exploited. Hard copy exploitation which is by far the most common method in use today--especially at tactical levels, involves trained specialists using optics and light tables to analyze prints, film, and transparencies.[7] Soft copy exploitation is a computer-aided geographic information system which allows the trained analyst to take full advantage of both spatial and spectral resolution.[8] Furthermore, soft copy--which can be obtained in a variety of formats (nine track tapes, high density diskettes, cassettes, or optical disks)--provides much more flexibility for both spectral analysis and the merging of MSI with other digital imagery.[9] This technique provides not only enhanced resolution but also the capability to factor in Defense Mapping Agency (DMA) map data and thus to produce perspectives from various azimuths, elevations, and distances.[10] Finally, soft copy exploitation allows the analyst to change spectral bands at will in order to use all aspects of the imagery.[11] It is by far the method of choice to use in order to more fully exploit MSI data with the many image enhancement techniques currently available.

Although a soft copy workstation using an IBM-PC/AT general purpose microcomputer or one of its compatibles with powerful image processing software is available for only about $40,000, unfortunately very few are found in operational units.[12] Most Army soft copy capability exists in the R&D and training environment and in each of the three topographic battalions.[13] The

Army Space Institute also has a soft copy capability which is used for demonstrations to promote MSI.[14]

OPERATIONAL USES

The Army is making some operational use of MSI today. As one might expect, the Army Corps of Engineers (CE) is the heaviest user since its activities most closely approximate those of the civil environment. Specifically, CE applies MSI for emergency operations; flood control and damage assessment; waterways management; mapping of wetlands habitats and agricultural land use; monitoring natural resources, suspended sediment distribution, and aquatic plant infestation; and coastal engineering.[15]

The Army's other operational uses of MSI have centered around terrain analysis as a function of the intelligence preparation of the battlefield (IPB). The Army's AirLand Battle doctrine has brought renewed meaning to and interest in IPB. The function of terrain analysis is to reduce the uncertainties of natural and man-made terrain features on military operations. Terrain analysis focuses on the military aspects of the terrain--known collectively as OCOKA. These include:

O - Observation and fields of fire

C - Cover and concealment

O - Obstacles and movement

K - Key terrain

A - Avenues of approach and mobility corridors.[16]

DMA uses six tactically significant terrain factors, which represent the natural and cultural features of landscape, to

evaluate the military aspects of terrain: slope, vegetation, surface materials, surface drainage, transportation, and obstacles.[17]

Although Army Field Manual 100-5, "Operations," states that "One of the best investments of the commander's time before battle is an intensive, personal reconnaissance of the terrain," this is often not possible.[18] Because of today's tremendous advances in mobility, lethality of weapons, communications, and information gathering devices--all producing an extended battlefield--commanders are frequently forced to rely on out-of-date or erroneous topographic maps, whose scales are often inadequate for military operations. Although successful execution of operations and survivability of soldiers and equipment are dependent on accurate terrain data, such data has not always been available. The U.S. Central Command's area of operations provides a good current example. However, MSI has demonstrated the capability not only to provide current, accurate maps but also to perform evaluation of the military aspects of terrain--both for any area of the globe.

Specific examples of tactical applications of MSI include identification of enemy countermobility operations and areas of nuclear, biological, and chemical contamination; estimation of cross-country mobility; prediction of dust generation; discrimination of targets and background; detection of camouflage; location of ground water in arid regions; analysis of landing zones, drop zones, airfields, and ports/harbors; acquisition of bathymetric data for amphibious assault planning;

augmentation, update, or substitution for maps; recognition of change; notation of seasonal effects; and determination of line-of-site clearances for communications and air space management systems and for electronic counter-countermeasures planning.[19] And these are only a few of the many possible tactical applications of MSI.

Without doubt, if MSI data were more readily accessible to the Army, it could serve many real-time operational and tactical needs.

ENDNOTES

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3. U.S. Department of the Army, Office of the Assistant Chief of Staff for Intelligence, Multispectral Imagery Letter of Instruction, p. 1 (hereafter referred to as "LOI").

4. Interview with Daniel W. Smith, U.S. Department of the Army, Office of the Assistant Chief of Staff for Intelligence, Washington, 20 October 1989.

5. LOI, p. 5.

6. Susan M. Davis, Tactical Uses of Multispectral Imagery, p. 2.

7. Wayne D. Zajac and Dan Smith, "Tactical Applications of Multispectral Imagery," Military Intelligence, April 1988, p. 34.

8. Ibid., pp. 33-34.

9. Davis, p. 2.

10. Zajac, p. 34.

11. U.S. Department of the Army, Office of the Assistant Chief of Staff For Intelligence, Army Multispectral Initiatives, p. 2 (hereafter referred to as "Army, ACSI").

12. Larry R. G. Martin, "Change Detection in the Urban Fringe Employing Landsat Satellite Imagery," Plan Canada, September 1986, p. 187.

13. Davis, p. 4.

14. Ibid., p. 6.

15. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Space-Based Remote Sensing of the Earth: A Report to the Congress, p. 16.

16. U.S. Department of the Army, Field Manual 100-5, pp. 76-80.

17. Stephen J. McGregor, Microcomputer Processing of Landsat Thematic Mapper Data for the Acquisition of Military Tactical Terrain Data, pp. 9-10.

18. U.S. Department of the Army, Field Manual 100-5, p. 24.

19. Davis, pp. 4-6.

Zajac, pp. 34-35.

Army, ACSI, pp. 1, 3.

U.S. Department of Defense, DoD Requirements For Multispectral Imagery And Design Recommendations For The Landsat 6 Follow-on System, pp. 7, 10, 11.

CHAPTER IV

FUTURE APPLICATIONS AND IMPLICATIONS TO THE ARMY

As with civil applications, Army use of MSI technology appears limited only by the resources and effort dedicated to it.

APPLICATIONS

Current plans call for a number of future efforts in enhancing MSI utilization in the Army. One involves the integration of satellite weather and MSI data.[1] Both systems use similar technology but with differing resolutions and frequency bands. Their integration would not only offer some very interesting products and capabilities but also assist in the IPB process by providing both terrain and weather analysis information. Another effort envisions the development of future military and civil satellite systems.[2] This effort led to the Army Multispectral Imagery Requirements Study, which identified Army MSI needs and the applications relating to them.[3] The study was designed to insure that the next generation of multispectral sensors and satellites meets Army requirements.[4] The Army is also investigating the feasibility of developing a future MSI tactical satellite based on the new "Lightsat" concept of smaller, less expensive, standardized satellite platforms.[5]

MSI technology may also be incorporated in the Military Man in Space Program.[6]

The Army training base is also upgrading its efforts to further the use of MSI. Currently, the U.S. Military Academy, the Defense Mapping School, and the Army Intelligence Center and School provide MSI instruction.[7] This instruction is currently being upgraded, and the Army Engineer School is also adding MSI to its curriculum.[8] The Army Space Institute is working with the Army Command and General Staff College to incorporate MSI into the studies of the Combined Arms and Services Staff School.[9] Every captain in the Army will thus learn of MSI capabilities.

The Multiband Collection and Analysis System (MCAS), currently described in a draft operational and organizational plan, envisions using a phased-approach, which will eventually provide a capability at the tactical level to receive MSI data directly from an MSI satellite (civil or military), process it, and distribute it to subordinate units, which may further process and reproduce it as required.[10]

If the military is successful in obtaining a tactical MSI satellite, a whole new range of uses might be developed. Near real-time locations of enemy units, damage assessment data, and friendly and enemy deception identification and evaluation represent just some possibilities. The Defense Advanced Research Projects Agency's "Assault Breaker" program might use the MSI satellite in its Joint Surveillance and Target Attack Radar System (JSTARS) which is to look several hundred miles behind the

enemy forward line of troops for command posts, airfields, armor formations, and surface-to-air missile sites.[11]

Even without a tactical MSI satellite, the Army should consider numerous potential uses of MSI. Certainly, the Army should consider integration of MSI data into the Tactical Exploitation of National Capabilities Program (TENCAP). This would at least automate the transfer of information to corps level. Another potential use is minefield detection.[12] Further, the Army should pursue the development of software templates or "fingerprints" to identify certain types of enemy units which set up in standard configurations--such as artillery batteries, air defense sites, and so forth. Archeologists have successfully used this technique to identify Mayan sites through the jungle foliage in the Yucatan.[13] Two other potential uses of MSI include the facilitation of search and rescue efforts and identification of areas of drug production.

IMPLICATIONS

The manifold implications of MSI for the U.S. Army have not yet been sufficiently explored. Although the civil MSI satellites are intended to gather information impacting on activities ranging from agriculture to urban planning, these same satellites collect data of military interest. Further, this imagery is publicly available. It has already been used to collect information from such areas as the Kola Peninsula, Chernobyl, and Krasnoyarsk.[14] As technology advances and one meter resolution becomes available (predicted by the end of this century), both

the commercial attractiveness and military capabilities of MSI will increase exponentially.[15]

The operational and tactical commanders must now worry also about an unseen threat to their overhead flanks--not just the enemy but also the news media. Maintaining secrecy during preparation and conduct of an operation will become much more difficult due to drastically increased vulnerability resulting from the combination of foreign military reconnaissance satellites and domestic and foreign civil MSI satellites. Army publications relating to operations security offer little guidance on countering this threat. Conventional practices such as non-radar reflective paints and special camouflage patterns on uniforms, vehicles, and nets are ineffective in mitigating MSI techniques. The Army R&D community is giving little attention to this problem.

COUNTERMEASURES

Several countermeasures are worthy of further investigation. Deception techniques may offer a partial solution. Also, satellites may be spoofed--interfered with electronically and made to shut down or change orbit. Likewise, jamming is a possibility as is the use of lasers to damage the optics or electronic components of the satellite. Shooting the satellite down or destroying its ground stations is an obvious response. However, these anti-satellite measures are quite serious with their employment being tantamount to a declaration

of war. One final countermeasure--quite practical and relatively easy to implement--is the dissemination of satellite vulnerability reports to the tactical commanders. These can be extremely valuable aids to operational security and deception planning. They tell the commander the period of time he is vulnerable to a particular satellite. With proper training he would then be able to implement and/or limit certain measures to reduce his vulnerability.

In summary, the future of MSI presents both great opportunities and critical problems for the Army.

ENDNOTES

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2. Ibid., p. 7.

3. U.S. Department of Defense, DoD Requirements for Multispectral Imagery and Design Recommendations for the Landsat 6 Follow-on System, p. 5.

4. Ibid., p. 2.

5. Davis, p. 7.

6. Ibid.

7. Ibid.

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9. U.S. Army Space Institute, Summary of the 27 June 1989 Army Multiband Imagery Working Group Meeting, p. 2.

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11. Paul A. Robblee, Jr., "The Army's Stake in Emerging Space Technologies," Parameters, December 1988, p. 116.

12. U.S. Army Corps of Engineers, Use of Texture Analysis Methods in the Characterization of Minefields and Background in High-Resolution Multispectral Imagery, p. 3.

13. Bill Lawren, "Mayans from the Sky," Omni, January 1985, p. 26.

14. Hugh DeSantis, "Commercial Observation Satellites and Their Military Implications: A Speculative Assessment," The Washington Quarterly, Summer 1989, p. 189.

Ann M. Florini, "The Opening Skies," International Security, Fall 1988, p. 99.

15. DeSantis, p. 189.

CHAPTER V

RECOMMENDATIONS AND CONCLUSION

The following recommendations are offered to improve the Army MSI program.

1. Obtain a senior leader to manage the Army MSI program and serve as its proponent. Efforts seem somewhat fragmented with some cohesion and articulation coming from the Army Multiband Imagery Working Group. The senior leader should be one who fully understands MSI and who has developed a "vision" of how MSI should fit into the Army plan. His leadership should provide the necessary direction and keep the program moving forward. His effort will be especially critical if MSI is to survive while competing with many other worthwhile programs during the upcoming defense budget reductions. As the Army combat developer for space systems, the Army Space Institute is the recommended organization to provide this leadership.

2. Improve the timeliness of MSI. Hopefully, the new MOU and accompanying LOI can be made to work within their advertised time lines. Efforts should also begin on developing methods of electronically passing MSI data instead of sending it through the mail. Continue pursuit of the MCAS as the objective method of solving the timeliness problem.

3. Get more image processing soft copy capability to the tactical units. The price is reasonable and should easily be returned through the positive results gained from the more flexible and local-oriented exploitation. The battalion S2 could

provide products tailored to meet the specific needs of his commander for a particular mission. What is the dollar value for increasing the probability of a successful mission with fewer casualties and less damaged equipment?

4. Continue and expand the promotion of MSI. Too many leaders in the Army have never heard of MSI, let alone know what it can do for them. This recommendation is extremely important. If MSI is going to survive in the competition with other programs in these times of reduced resources, it must gain the support of the "warfighters."

5. Increase Army efforts in MSI development. Push for the various enhancements such as hyperspectral sensors and improved resolution in both the civil and military programs. Pursue studies aimed at specific military applications such as minefield identification through MSI.

6. Study the countermeasures problem. In the interim, at least add the civil MSI satellites to the existing satellite vulnerability reports and require the reports to be disseminated to battalion-level. In addition, educate the tactical commanders on their use to include the capabilities of the various satellites. Also, provide training on what the commanders can do using current techniques to mitigate the effects of MSI and reconnaissance satellites.

In conclusion, MSI can offer tremendous benefits to enhance the Army's conduct of the AirLand Battle. However, it is a struggling, relatively new technology (at least to the Army) in the hands of those who are not considered the power brokers of

the Army. The technology is arriving at a time of increasing budget pressures with corresponding reductions in resources and manpower. Its future is far from secure. Hopefully with concentrated efforts, the fruits which MSI can provide the Army will be realized, understood, and supported by the senior leadership of the Army.

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